Applied Health Physics Qualifier
Fall 2010

1. (15 minutes). Describe and plot the absorbed dose profile in water for the following radiation beams and describe the associated ($D_{max}$, Bragg-peak, bremsstrahlung, etc.):

a) Low energy photons used in diagnostic radiology (less than 250 kV)
b) High energy photons used in therapeutic radiology (i.e. Co-60, 6 MV, 10 MV and 22 MV),
c) High energy electrons,
d) Neutrons at 10 MeV,
e) High energy charged particles (i.e. protons, carbon ions, and deuterons).

2. (20 minutes)
   a. (15 min) Calculate the absorbed dose to a tissue due to alpha particles when just 10% of the cell nuclei in the tissue are hit by an alpha particle. Assume that the average path length through the cell nucleus is 6 micrometers, the diameter is 9 micrometers, and the alpha particle stopping power is 100 keV/µm. (1eV=1.6x10^{-19}J)

   b. (5 min) At the dose calculated above, what is the approximate number of electron events per cell nucleus in a tissue exposed to $^{60}$Co gamma rays? How does this impact the determination of RBE for alpha particles if you consider individual cells?

3. (15 minutes) Radioactive noble gases arise in engineered systems such as nuclear power reactors and in the natural background such as $^{222}$Rn in the $^{238}$U decay chain. Since they essentially never form compounds and are only slightly soluble, their incorporation in human tissue is not a major concern. Nevertheless, the EPA has established 4 pCi/l of $^{222}$Rn in air as the “action” level for human habitations, meaning remediation is required if higher levels are present.

   a. (7 min) Explain why $^{222}$Rn, and presumably other noble gases at this activity level, could be health concerns, i.e., what specifically is the physical hazard?

   b. (8 min) Based upon your answer to (a), explain why room air with a high mass loading of suspended particulate matter would provide some protection for a person in that room from the radiological hazard of a relatively high level of airborne radioactive noble gas atoms.

4. (10 minutes) Explain what information would be necessary (and why this information would be necessary) to perform a detailed fetal dose assessment for maternal radionuclide burdens that were introduced during gestation.

5. (20 minutes) Internal dose assessment uses several definitions of dose. Define the following:
Dose Equivalent, Effective Dose Equivalent and Committed Effective Dose Equivalent.
Include the formulation for calculating these types of doses and define the factors upon which these depend. Then discuss the impact of Reference Man on each of these quantities.

6. (20 minutes) $^{41}$Ar emits a 1293 keV gamma 99.1% of the time. From the information below calculate the submersion dose rate for a half-infinite volume of gas, i.e., the dose to someone on the ground submerged in an infinite cloud that has $S$ bq/m$^3$ uniform source strength.

Information:

\[
\begin{align*}
\frac{\mu_{en}}{\rho} \text{(air)} &= 0.242 \text{ cm}^2/\text{g (at 1293 keV)} \\
\frac{\mu_{en}}{\rho} \text{(tissue)} &= 0.0265 \text{ cm}^2/\text{g (at 1293 keV)} \\
\frac{\mu}{\rho} \text{(air)} &= 0.147 \text{ cm}^2/\text{g (at 1293 keV)} \\
\frac{\mu}{\rho} \text{(tissue)} &= 0.160 \text{ cm}^2/\text{g (at 1293 keV)} \\
\text{density of air} &= 0.00129 \text{ g/cm}^3 \\
\text{density of tissue} &= 1.0 \text{ g/cm}^3
\end{align*}
\]

7. (20 minutes) Answer the following questions regarding the design of the shielding for an electron accelerator facility using the information given below. Use the figures copied from the NCRP 51 (1977), Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities, below.

Electron beam kinetic energy (E) = 20 MeV
Peak current (I) = 1 A
Beam pulse length (L) = 1 µs
Beam pulse frequency (F) = 10 Hz

The target is a tungsten beam dump. (Z tungsten = 74)

a. (15 min) Assume that the average dose equivalent rate in an office, which is at 90° from the beam line and 5 meters from the target (perpendicular distance from the beam line), needs to be no greater than 0.5 mrem/h. Calculate the minimum thickness required for the concrete wall (density is 2.35 g/cm$^3$) between the target and the office.

b. (5 min) Assume that in part (a) the required transmission factor is $10^{-4}$ and the existing concrete wall is 2.5 feet. Calculate the additional lead thickness required to complement the concrete wall.
Figure 1. X-Ray Emission Rates for High-Z Targets
Figure 2. Equivalent Incident Electron Energies

Equivalent electron energy for analysis of transmission of x-rays emitted in the 90° direction from very thick high-Z targets, as a function of the incident electron energy. The x-ray spectrum at 90° is lower in energy than the spectrum at 90°. This lower-energy radiation can be described in terms of an incident electron energy that would in effect produce x-rays with similar transmission characteristics in the 0° direction. Transmission curves or tenth-value layer curves applicable to the lower energy selected from this graph may be used in the calculation of shielding thicknesses for the 90° beam. The same procedure would be a conservative approach for x-rays from low-Z targets, and for x-rays emitted in the 190° direction. References: (1) Burrill (1968); (2) and Seltzer (1970); (3) McCall and Nelson (1974); and (4) Saxon (1964).
Transmission of thick-target x rays through ordinary concrete (density 2.35 g/cm\(^3\)), under broad-beam conditions. Energy designations on each curve (0.5 to 176 MeV) refer to the monoenergetic electron energy incident on the thick x-ray producing target. Curves represent transmission in dose-equivalent index ration. (See Appendix E-12 for basis for interpolating between curves.) Curves derived from (1) Miller and Kennedy (1956); (2) Kirn and Kennedy (1954); (3) Karzmark and Capone (1968); and (4) NCRP Report No. 34 (NCRP, 1970a) and NCRP Report No. 49 (NCRP, 1976).
Figure 4. Dose-Equivalent Index Tenth-Value Layers for Broad-Beam X Rays in Lead

Dose-equivalent index tenth-value layers in ordinary lead (density 11.3 g/cm$^3$) for thick target x-rays under broad-beam conditions, as a function of the energy of electrons incident on the thick target. The dotted curve refers to the first tenth-value layer; the solid curve refers to subsequent or "equilibrium" tenth-value layers. Both curves are empirically drawn through data points derived from the following references: (1) Miller and Kennedy (1956); (2) Maruyama et al. (1971); (3) ICRP Publication No. 4 (ICRP, 1964); and (4) NCRP Report No. 34 (NCRP, 1970a). The empirical curve is not extended into the 10- to 100-MeV region because of uncertainties in the available data.